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THE DETERMINATION OF COLLISION BULKHEAD POSITION BY USING CONSIDERATION OF SHIP GROUNDING ANALYSIS

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ABSTRACT

The ship collision case is an accident involving ship to ship damage or a ship damage only. An approach carried out to determine the effect of ship collision is by using numerical methods. Usually, an experiment method is used to verify the result of numerical method with the same model. The numerical method is based on the fundamental theories of explicit dynamics which the response of contact model is presented by time series. The ship and ground models are modeled in finite element software package. In order to obtain the same result between simulation and real condition, the ship is applied move forward to ground model. The internal energy is captured so that the stiffness of striking ship construction can be measured from this result. The ground model is assumed by using rigid body which means that the deflection and stress during simulation is neglected. From the result, it can be concluded that the effects of bulkhead position is in the 4.0 m from forepeak of ship. This position has considered that the ground model does not touch the bulkhead.

KEYWORDS: Ship collision, Numerical Method, Explicit Dynamics, Experiment & Penetration

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Original Article

INTRODUCTION

Indonesia is the largest archipelagic nation in the world which has many potential and on the other side, threat. Indonesia has coastline stretching over 95,000 km and around more than 17,000 islands. It cannot be denied that Indonesia sea region has many coral reefs. Moreover, Indonesia has 18% world coral reefs, so coral is the most things that we will find in the sea region of Indonesia [4]. On the other side, the existing of coral reefs threatens either the safety of ship and the passengers or the coral reefs itself. The grounding ship caused by coral reefs is the most likelihood incidents happened. One of the ships which grounded cause by coral reefs is 2009 USS Port Royal. The ship of US Navy hit coral reefs in Oahu, Hawaii. [6]

It is complicated to fix the grounded ship on the water. The most probable thing is taking the ship to the closest shipyard or port than fix it there. So, it is immensely important to make a further research about the determination of forepeak bulkhead position with consideration of the ship grounding analysis. The research will be useful to reduce the effect of ship leakage caused by coral reefs so that the ship still can sail to the closest port or shipyard. [7]

LITERATURE REVIEW

Collision analysis models were first developed for analyzing the design of ships transporting nuclear materials. The “worst case” was considered by the total inelastic right angle collision with the struck ship. That’s why, the majority of currently available models deliberate only right angle collisions. Furthermore, there is an

assumption that the kinetic energy parallel to the struck ship's centerline is negligible [9]. The empirical method is Minorsky Method and the approach is based on these judgments: The characteristic of collision is totally inelastic; If there is some kinetic energy along the struck ship's longitudinal direction, it can be ignored because that is trivial; It can be disregarded about the rotations of the struck and striking ships, because they are minor.

The low energy collisions that do not cause the rupture of side shell is the main problem of the Minorsky method. Then, to correct the limitation of Minorsky's Method at the low energy, several approaches have been developed [10]. In 2012, the research about the simulation of ship grounding damage using the finite element method (FEM) was ever carried out the analysis. The result showed that Finite Element Analysis (FEA) is an appropriate tool which can be used to investigate the local and global behavior of a ship's structure during grinding, FEA has also provided good models for prediction material rupture. But the model should include appropriate scaling laws to take account of mesh size sensitivity effect. Figure 1 shows the larger draught will cause the larger vertical penetration.

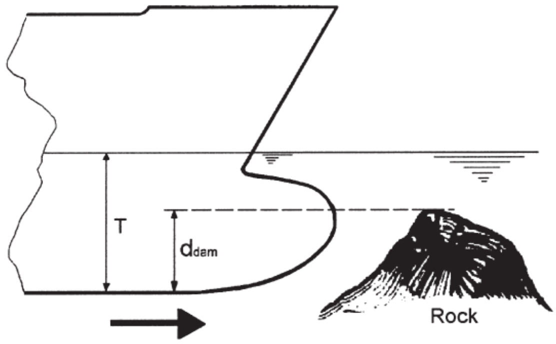


Figure 1: The Relationship between the Grounding Model and Ship Draught

The previous researcher also stated that numerical simulations are cheaper to run than experimental studies. Even there are still significant requirements to make sure that the quality of the experimental studies is a good quality one. Furthermore, the results of simulation used FEM are still needed to be validated using another numerical simulation model in predicting structural responses during collision and grounding. This comparison will ensure the result of simulation being more valid [3].

RESEARCH METHODS

Finite Element Method

A finite element method (abbreviated as FEM) is a numerical technique to acquire an approximate solution to a class of problems governed by elliptic partial differential equations. The problems are known as boundary value problems. The FEM alters the elliptic partial differential equation and becomes a set of algebraic equations which requires effortless to solve. The initial value problems that consist of a parabolic or hyperbolic differential equation and the initial conditions cannot be completely solved by the finite element method or need another numerical technique. To alter the time or temporal derivatives into algebraic expressions, it requires another numerical technique like the finite difference method (FDM). Thus, solving an initial value problem requires both FEM and FDM [2]. The Finite Element Analysis means that FEM can understand the physical behaviors of a complex object such as: strength, heat transfer capability, fluid flow, etc. FEM also can predict the performance and behavior based the design. The last purposes are calculating the safety margin and identifying the weakness of the design accurately.

As a software operation, FEM has advantages than other numerical methods, here are some of them included: 1) The method of FEM can be used for any irregular-shaped domain and all types of boundary conditions, 2) The Domains that consist of more than one material can be easily analyzed with FEM, (3) The accuracy of solution of FEM can be improved either by choosing approximation of higher degree polynomials or by proper refinement of the mesh, (4) the algebraic equations of FEM can be easily generated and solved on a computer, and (5) FEM can handle a wide variety of engineering problems such as: solid mechanics, fluids, dynamics, heat problems, electrostatic problems[5].

On the other hand, FEM also has disadvantages here: (1) The method is not producing a general closed-form solution, which would permit one to examine system response to change in various parameters, (2) The result got in the calculation of FEM obtains only approximate solutions, (3) Sometimes, the FEM has inherent errors, and (4) The mistakes caused by users can be fatal for the calculation.

Empirical Method

The collision analysis models were first developed for analyzing the design of ships transporting nuclear materials. The “worst case” was considered by the total inelastic right angle collision with the struck ship. That’s why the majority of currently available models deliberates only right angle collisions. Furthermore, there is an assumption that the kinetic energy parallel to the struck ship’s centerline is negligible [1].

Furthermore, the Minorsky’s approach is based on some judgments as follows: (1) The characteristic of collision is totally inelastic, (2) If there is some kinetic energy along the struck ship’s longitudinal direction, it can be ignored because that is trivial, and (3) It can be disregarded about the rotations of the struck and striking ships because they are minor. The judgments number 1 and 2 determine what we called “worst case”. The judgment number three is based on the observation. It is valid only small rotations in actual collisions during the damage event as well as small rotations have also been studied in theoretical analysis. With these judgments, the system becomes one dimensional [11]. The final velocities of both struck and striking ships can be derived as the Equation 1.

$$(M_A + M_B + dm_A)v = M_B v_B \tag{1}$$

$$\Delta KE = \frac{1}{2} M_B v_B^2 - \frac{1}{2}(M_A + M_B + dm_A)v^2 \tag{2}$$

$$\Delta KE = \frac{M_A M_A}{2M_A + 1.43 M_B}(v_B \sin\theta)^2 \tag{3}$$

Where M_A is defined with mass of struck ship, M_B is defined with mass of striking ship, dm_A is defined with added mass of struck ship in the sway direction, v is defined by final velocity in the Y direction to the struck ship’s centerline and v_B is defined with initial velocity of the striking ship in Y direction. So, the value of total kinetic energy absorbed in the collision ΔKE , can be shown in Equation 2. The Minorsky figured the added mass in sway, dm_A to be 0.4 M_A. In order to reckon the velocity of the striking ship in the sway direction of the struck ship, the collision angle, θ, is introduced. To reckon the absorbed kinetic energy in the struck ship transverse direction, use the Equation 3. Where v_B is the initial velocity of the striking ship. It is immensely important to be noticed that a right angle collision may not be the “worst case” anymore. So, the equations (1) and (3) may ignore the kinetic energy lost in collisions at aslant angles (by the

bow) and/or when the struck ship has forward speed. In some case, when ship struck at right angle than aslant angle the side structure may also offer more resistance.

RESULT AND ANALYSIS

Generally, the explicit dynamic analysis is always carried out by using 2 (two) models separately as contact and target. The ship striking a ground model is a kinematic hardening material, because the failure construction caused by the excessive stress from collision simulation can be known obviously. Table 1 shows the kinematic hardening material for the striking ship. The speed of striking ship has the forward direction and is set to the constant velocity. In order to obtain the initial momentum, the striking ship mass is 420 tons which is the total mass of lightweight and deadweight. The kinetic energy of striking ship needs to be calculating previously.

Table 1: The Kinematic Hardening Material for the Striking Ship

No.	Parameter	Value	Dimension
1.	Density	7850	kg/m^3
2.	Elasticity Modulus	210	GPa
3.	Poisson Number	0.3	-
4.	Yield Stress	315	MPa
5.	Tangential Modulus	625	MPa
6.	Hardening Parameter	0	-
7.	Strain Rate (c)	32	1/s
8.	Strain Rate (p)	5	-
9.	Failure Strain	0.325	-

A ship construction is similar to a plate which has stiffener. This model is aim to increase the strength of ship construction either for the collision cases or the other cases such as the longitudinal strength. To prove that the ship construction is able to withstand the initial collision, the pressure contact which does relate to the stress concentration experienced by the contact point is greater than the yield stress so that the construction is failure.

Table 2: The Kinetic Energy of Striking Ship in Several of Ship Speed

No.	Speed (knot)	Kinetic Energy (MJ)
1.	6	1.99
2.	8	3.54
3.	9	4.48
4.	10	5.54
5.	12	7.98

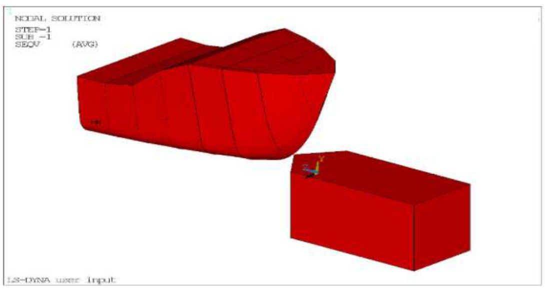


Figure 2: The Grounding Model and Striking Ship

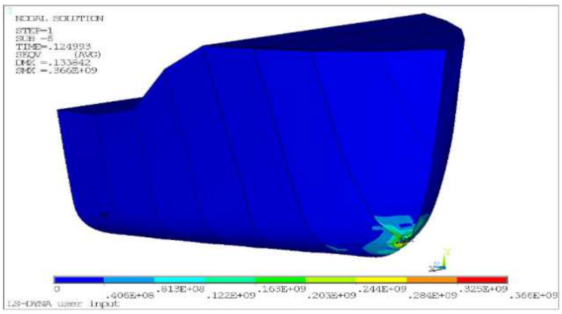
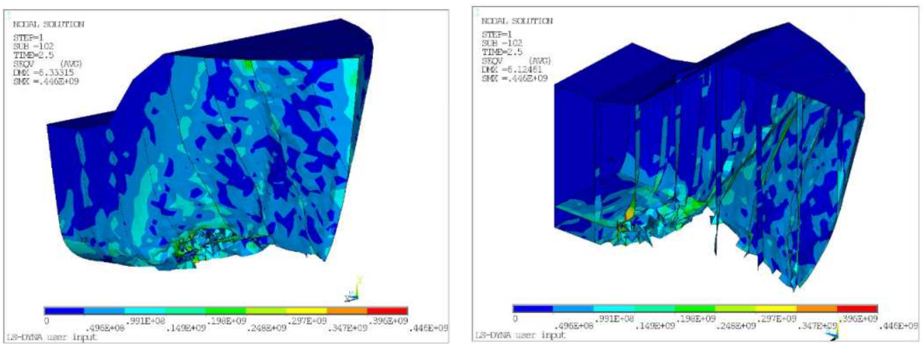


Figure 3: The Initial Stress Caused by the Initial Contact

Table 2 shows the kinetic energy of striking ship in the several of ship speed. From that table, it can be known that the kinetic energy is getting greater in the increase of ship speed. The ground model is as rigid body which it means that the stress and deformation experienced by the model is ignored. The model does not move and the boundary condition is fixed in the translation and rotational motion. By using this boundary condition, the ground model will not move although the kinetic energy that works is relatively large. Figure 2 shows the 2 (two) models of grounding and striking ship.

The fore peak of striking ship will first experience the stress concentration in the initial contact. The stress will be distributed in the other constructions later on because the deflection or deformation of plate and profile will be change caused by the dynamic analysis. Figure 3 shows that the stress occurred affected by the initial contact when the striking ship touches the grounding model. The initial momentum of striking ship can determine whether the construction is damage or not. Shortly, the momentum is dangerous if it is applied excessively. The extent of damage is predominantly caused by the kinetic energy of striking ship. This energy will be absorbed by the ship construction. If the energy is excessive, the stress will be greater and destroy small or large part of construction. From Figure 3, the maximum stress occurred is 365 MPa which the yield stress that can be shown in Table 2 is 315 MPa. It means that the construction is definitely damaged and proven by the simulation.

Figure 4 (a) shows the outside view of striking ship damaged the hull. Figure 4 (b) shows the inner view of striking ship damaged the plate and profile. The damage shape is same with the grounding model. The stress distributed in the whole modeled ship affects the magnitude of plate and profile deformation. From Table 2, the failure strain is 0.325 which is damaged if the deformation is more than that.



(a) **(b)**

Figure 4: The Damage Shape of Striking Ship in the Outside View and (b) in the Inner View

The curved plate, especially for the forepeak hull, will increase the internal energy of ship construction.

Furthermore, the longitudinal bulkhead will contribute to enhance the internal energy by pressing the grounding model to make the deeper penetration. Each of the construction either plate or stiffener, it has the same material properties but the treatments of damage shape are difference. The yield stress and failure strain is same but the normal plane that does probably create a bending and buckling plate is depend on the contact position. This is the crucial condition which the damaged construction will determine whether the penetration touches the collision bulkhead or not. The kinetic energy absorbed by the striking ship will affect the magnitude of penetration.

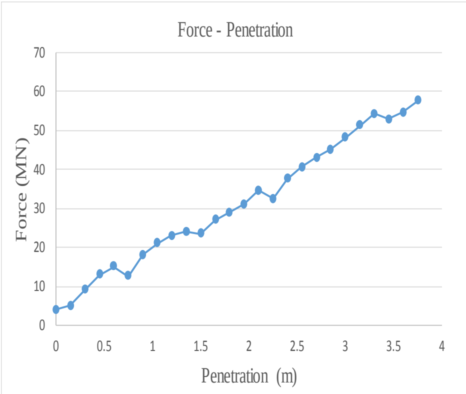


Figure 5: The Relation between Force and Penetration of Ship Grounding Model

Figure 5 explains the relation of force and penetration during the grounding case occurred. These simulations run until the penetration of 4.0 meters from the initial contact. Generally, the interval of 0.75 meters shows that the force has decreased. It means that the ship construction of the forepeak has tried to resist the penetration in order to not be deep. The maximum force is about 60 MN where the greatest contact between ship construction and grounding model is occurred. The construction will be bended and deformation in elastic area so that the force is more increase than previously. When the construction is failure, the force has reduced because the stiffness is also failure. This phenomenon is always occurred during the grounding case until the internal energy is same with the kinetic energy of striking ship.

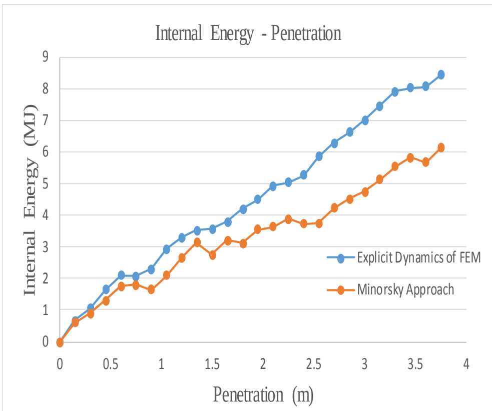


Figure 6: The Internal Energy during Ship Grounding

The explicit dynamics of finite element method and Minorsky's approach are the method usually used to comply the ship collision and grounding problem which are shown in Figure 6. Minorsky's approach needs the area damaged in order to be inserted in the formula. The area damaged can be easily obtained by equating of the grounding model penetrated. The result of internal energy produced from Minorsky's approach is lower that the explicit dynamics of finite element method (FEM) because the FEM model is made completely including plate and stiffener in this simulation.

The result obtained will be more accurate. The purpose using Minorsky's approach is to ensure that the graph has the same pattern with the explicit dynamics of FEM. At the penetration of 4.0 meters, the internal energy is 8.5 and 6.2 MJ for the explicit dynamic of finite element method and the Minorsky's approach respectively. The difference in value between two methods is about 37.09% which it is more value for the comparison. But, the difference in value of two methods is not more significant if the penetration is not too deep which 1.5 to 2.0 meters is

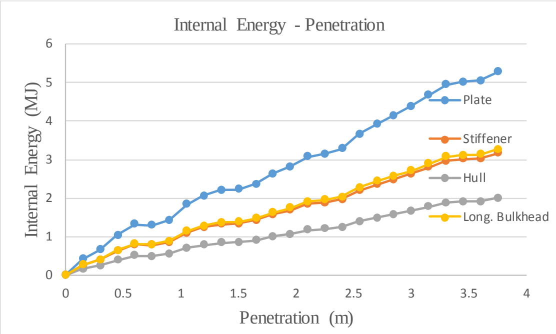


Figure 7: The Internal Energy in Each of Plate, Stiffener, Hull and Longitudinal Bulkhead

Figure 7 shows the internal energy in several of plate, hull, stiffener, and longitudinal bulkhead. Plate consists of hull and longitudinal bulkhead. Stiffener comprises ordinary frame, web frame, center girder, and side girder. These parts are commonly used to determine the contribution of each component for the internal energy. From Figure 6, it can be observed that the plate has the greatest value of internal energy than stiffener. The biggest contribution of internal energy is owned by the longitudinal bulkhead. Almost 62% of the internal energy of plate is possessed by the longitudinal bulkhead. The position of this component does certainly support to hold up the penetration. The internal energy of longitudinal bulkhead is nearly same with the stiffener. The model of center and side girders had by the stiffener does also surely resist the damage penetration.

The magnitude of penetration can be simple calculated by using the energy conservation related to the internal energy of striking ship. Because the ship speed does not ever move in the constant velocity in the real condition, it is assumed as the constant speed for this analysis. Each of penetration has the magnitude of internal energy so that the stop criteria are determined by the same of internal energy and the initial kinetic energy.

Table 3: The Relation between the Maximum Speeds of Ship and The Maximum Penetration

No.	Speed (knot)	Kinetic Energy (MJ)	Maximum Penetration (m)
1.	6	1.99	0.75
2.	8	3.54	1.42
3.	9	4.48	1.95
4.	10	5.54	2.51
5.	12	7.98	3.72

From the Table 3, it can be concluded that the damage penetration to the collision bulkhead is happened in the ship speed of 12 knot. The preliminary design of a striking ship has the width of the collision bulkhead of 3.5 meters. So if this design is applied, the collision bulkhead will be damaged. Definitely, the width of collision bulkhead is based on the agreement between the designer and the owner. If the ship is operated in the maximum speed of 12 knot in the coral area, the width of collision bulkhead is 4.0 meters by considering the penetration effect. The maximum ship speeds are 6, 8, 9,

and 10 knots which the maximum penetrations are 0.75, 1.42, 1.95, and 2.51 meters respectively.

CONCLUSIONS

- The Minorsky's approach is not appropriate to be used for greater penetration and damage area. Because the finite element method is the sophisticated method to comply the construction problem and the advance method to be applied in several materials and mechanic cases, this method is recommended to be used for the ship grounding analysis. Beside it, experimental test is definitely the most accurate method, but it is difficult to be applied to be carried out the grounding experiment because the material models that have to be prepared have to the real scale model;
- The most dominant internal energy is to be increased by the enhancement of longitudinal bulkhead dimension, because it gives more contribution of the internal energy strength. Later on, the center and side girder can be treated same as the longitudinal bulkhead to be greater than the previous design. If the increases of hull thicknesses are carried out, the effect of internal energy does not give more contribution to improve the strength, and
- At the operational area of coral reef, the recommended ship speed is 10 knots in order to avoid the damaged collision bulkhead. By considering the magnitude of penetration, this ship will be safe to be operated in this speed.

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